ORINCON CORPORATION

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ADVANCED SUBMARINE TECHNOLOGY PROGRAM

Final Report

31 May 1991

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The following report gives an overall description of the capabilities of the DARPA Submarine Hydrodynamics/Hydroacoustics Technology Center (SH/HTC). Specifically, the need for the SH/HTC to address complex hydrodynamic and hydroacoustic submarine design problems and the concept of operation of the Center are discussed. The charter establishing the Center and the Center's objectives are described. The hardware and software capabilities of the Center as well as the facility setup are described in detail.

The four main technical areas of study being addressed by the SH/HTC are propulsor/hull flow, maneuvering, hydro/structural acoustics, and special studies. The problems associated in understanding these areas are described along with a description of the corresponding solutions and topics of research to be undertaken by the SH/HTC. Both past and current engineering R&D activities in the four main technical areas of study are described. Also, a detailed summary of experiments conducted is included in Appendix A.

Lastly, future plans covering the expansion of the Center's computational capabilities, both hardware and software, are discussed. Planned research activities at the SH/HTC are also described.

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EXECUTIVE SUMMARY

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Contract No. Subcontract No. S01500

on

A Description of the Capabilities of the DARPA Submarine Hydrodynamics/Hydroacoustics Technology Center (SH/HTC)

to

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May 1991

1.0 INTRODUCTION

The Defense Advanced Research Projects Agency (DARPA) is sponsoring and managing the Advanced Submarine Technology Program (ASTP). The main purpose of the program is to develop crucial technologies to be incorporated into the post SSN 21 submarine design efforts. Specific objectives of the ASTP are:

- Identification and development of promising and revolutionary technology to initiate the emergence of innovative design options for future U.S. submarines
- Mobilization and focusing of the industrial, university and Government R&D base to improve future submarine performance
- Demonstration of significant technologies and systems through rapid prototyping.

2.0 SH/HTC CONCEPT OF OPERATION

The SH/HTC is an integral part of the DARPA ASTP Hydrodynamics Program. The concept of operation of this facility is to use all of the available tools required in an integrated fashion to solve complex hydrodynamic and hydroacoustic submarine design problems. This section describes the rationale, charter, and objectives of the SH/HTC and further describes the manner in which the Center is intended to operate.

2.1 Establishment of SH/HTC

The Submarine Hydrodynamic/Hydroacoustic Technology Center (SH/HTC) was established to focus experimental and computational efforts in the areas of hydrodynamic stability and control, hydroacoustic noise generation and suppression, and propulsor performance. With the integration of the advanced computational capabilities of this facility in several diverse and independent technical areas, efficient validation of computational codes and planning of subscale experiments can be achieved with less reliance on full-scale trials. Further advantages of the Center include reduced cost, time to complete full design cycles, and implementation of proven innnovative developments into the Navy.

The rationale for the existence of the SH/HTC is supported by what the Center provides and its corresponding operational considerations. Foremost, the Center can provide designs outside historical envelopes leading to the development of innovative new concepts. The need for platform redesign and modification in addition to design considerations involving ship safety and load prediction is fulfilled by the capabilities of the Center. Through the SH/HTC's work, new threats and missions, and new technology can be identified. In terms of operational considerations, the Center is a centralized, accessible site which can also be accessed by secure remote link, if required. Finally, the Center can function as an independent organization for integrating new technology into design application tools.

2.2 SH/HTC Charter

The development, operation, maintenance, and transition of the SH/HTC is ensured by the David Taylor Research Center (DTRC) and DARPA. Specific responsibilities of DTRC and DARPA, as listed in the charter are:

DTRC will:

- Provide administrative and technical support, utilities, and secure space to house the Technology Center and library
- Provide for access to experimental data bases at the GENSER level
- Facilitate coordination of Navy technology base efforts with DARPA to maximize benefits and avoid duplication of effort
- Foster and promote end-user participation in experimental planning in order to provide data for code validation
- Assist in the evaluation of code performance and make recommendations to DARPA
- Provide DARPA a transition plan to DTRC to accept full responsibility for the Center's maintenance and operation.

DARPA will:

- Acquire, install, and integrate the necessary computer hardware, software, and peripheral equipment to establish the Technology Center
- Transfer title to the DARPA procured equipment to DTRC by the end of FY 92
- Designate a Technical Director of the Technology Center with the management and technical responsibility to fulfill the above objectives (The designated Technical Director will report to the DARPA Program Manager.)

- Coordinate with other pertinent Navy and DARPA programs to avoid duplication and assure mutual sharing of results
- Provide funding within available resources for the development, testing, and evaluation of the Technology Center through transition to the DTRC.

2.3 SH/HTC Objectives

The SH/HTC essentially has two major objectives. The first objective is to perform research and development activities in order to increase the fidelity of analysis tools to a level required to resolve critical issues in four main technical areas of study:

- Submarine hull flow and propulsor-hull interaction
- Submarine maneuvering
- Hydro/structural acoustics
- Special studies.

The second major objective of the Center is the integration of tools among the different technical areas/disciplines to support rapid prototyping.

The approach taken by the SH/HTC in support of the two main objectives and in the development, evaluation, validation, and application of integrated submarine hydrodynamic/hydroacoustic technology includes the following:

- Acquiring and integrating computer hardware and software at DTRC for the Technology Center
- Concentrating resources available to the submarine community to focus efficiently on those problem areas that are the most important and pressing impediments to improving submarine performance
- Providing access to the Center for appropriate government, industry, and university representatives of the submarine design community through the establishment of secure nodal workstations
- Incorporating artificial intelligence techniques and advanced man-machine interface by using an expert shell executive module

- Establishing and maintaining a technical library and experimental data base that is resident in the Technology Center and that can be used for code validation and performance tradeoff analyses
- Defining, standardizing, and documenting technical terminology and database formats in order to facilitate multi-user applications
- Providing for expeditious transfer of proven developments and facilities to the Navy.

3.0 SH/HTC CAPABILITIES AND FACILITY DESCRIPTION

This section describes the hardware and software capabilities of the SH/HTC. In addition, a description is provided of the research activities being conducted in the four main technical areas.

The conventional approach in analyzing a flow problem is a two step iterative process. Prediction of the performance using free-running models is the first part of the process followed by the replication of "problem" trajectories using free-running models. This process is repeated until optimization of the model is achieved; that is, the model closely resembles the actual flow in question. Unfortunately, this conventional approach does not stress the understanding of the fundamental physics of the flow. Even if the flow is reliably modeled, the extrapolation of results to other configurations or technologies (i.e., propulsors, hydroacoustics, etc) is not very likely. Finally, due to the iterative nature of this approach, investment is limited to short-term problems since long-term problems would be too costly to analyze.

The Submarine Hydrodynamic/Hydroacoustics Technology Center's approach involves three basic steps. The first vital step is the complete understanding of the physics involved in the cases of cross-flow separation, vortex interactions, scaling effects, appendage stall, vortex tracking, wake-propeller interaction, and propulsor effects. Once the physics is understood, a hierarchy of computational techniques such as coefficient-based models, aerodynamic panel models, and Navier-Stokes solutions are applied to model the problem being analyzed. The third step is the development of advanced experimental techniques. Validation of the computational techniques is accomplished through the comparison of experimental data obtained using experimental techniques such as laser doppler velocimetry and particle displacement velocimetry. A diagram of the integration of the SH/HTC into the design process is shown in Figure 1.

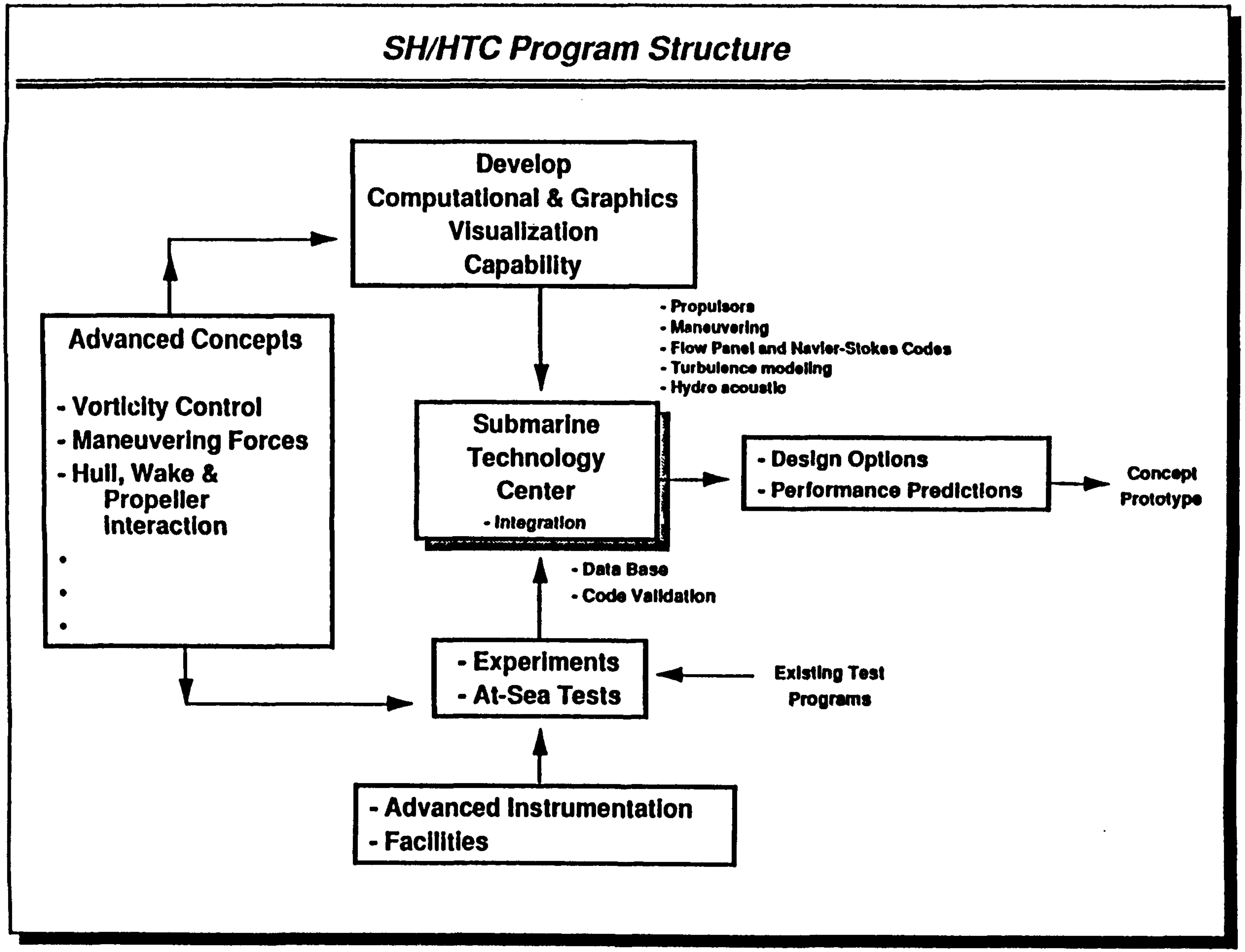


Figure 1. Integration of SH/HTC into Design Process

3.1 SH/HTC Hardware Configuration and Supporting Software

The SH/HTC runs a self-contained, classified, computing facility located in Building 17E, Room 120, at David Taylor Research Center (DTRC). The room, designated as a vault, has been approved for open storage at the SECRET level. A floor plan of the facility is shown in Figure 2. As seen in the figure, the Center consists of environmentally separate computer and I/O device rooms. Each of the principal areas of study (i.e., maneuvering, hydroacoustics, etc) has a specific designated work area with access to the computers conveniently located in a "user area". The management and technical direction of the SH/HTC is done completely within the Center itself.

The Center's computer configuration is shown in Figure 3 where it is seen that the computer setup is interconnected by a thin wire local area network utilizing power-to-point RS232 and parallel cabling. The heart of the network is a CONVEX C220 which contains two CPU's. The speed of the C220 may be seen in Table 1 where timing studies comparing calculations performed on a Cray 2, a Cray XMP, and the CONVEX C220 are presented.

TABLE 1. TIMING COMPARISON BETWEEN CRAY AND CONVEX C220 COMPUTERS

		CPU	Wall Clock
DTRC IFLOWS 30,625 grid points	Cray-2 CONVEX C220	41.7 min 162.8	73.0 168.6
Iowa RANS 211,222 grid points	Cray-XMP CONVEX C220	20 89.9	82 90.6

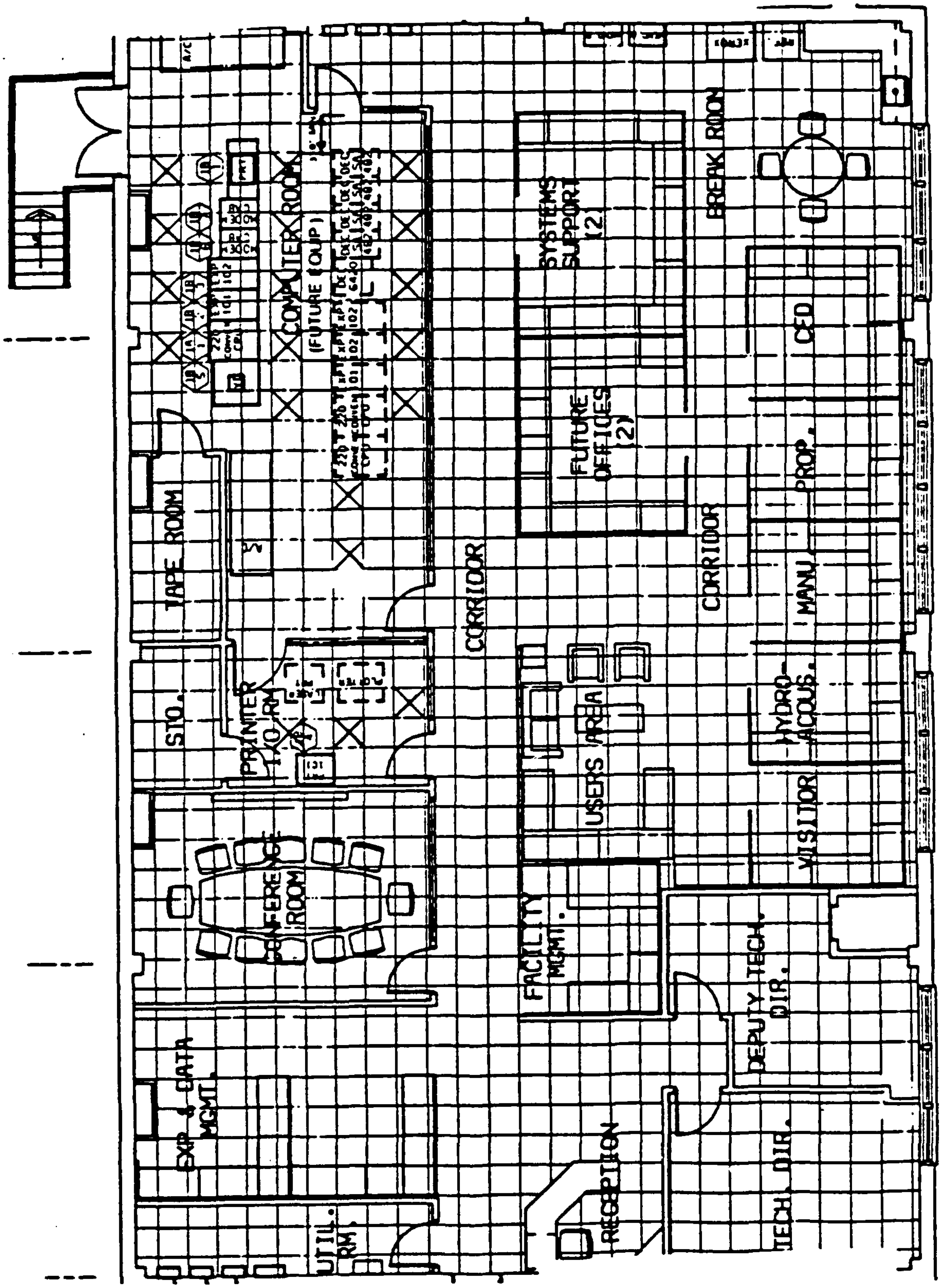


Figure 2. SH/HTC Floor Plan

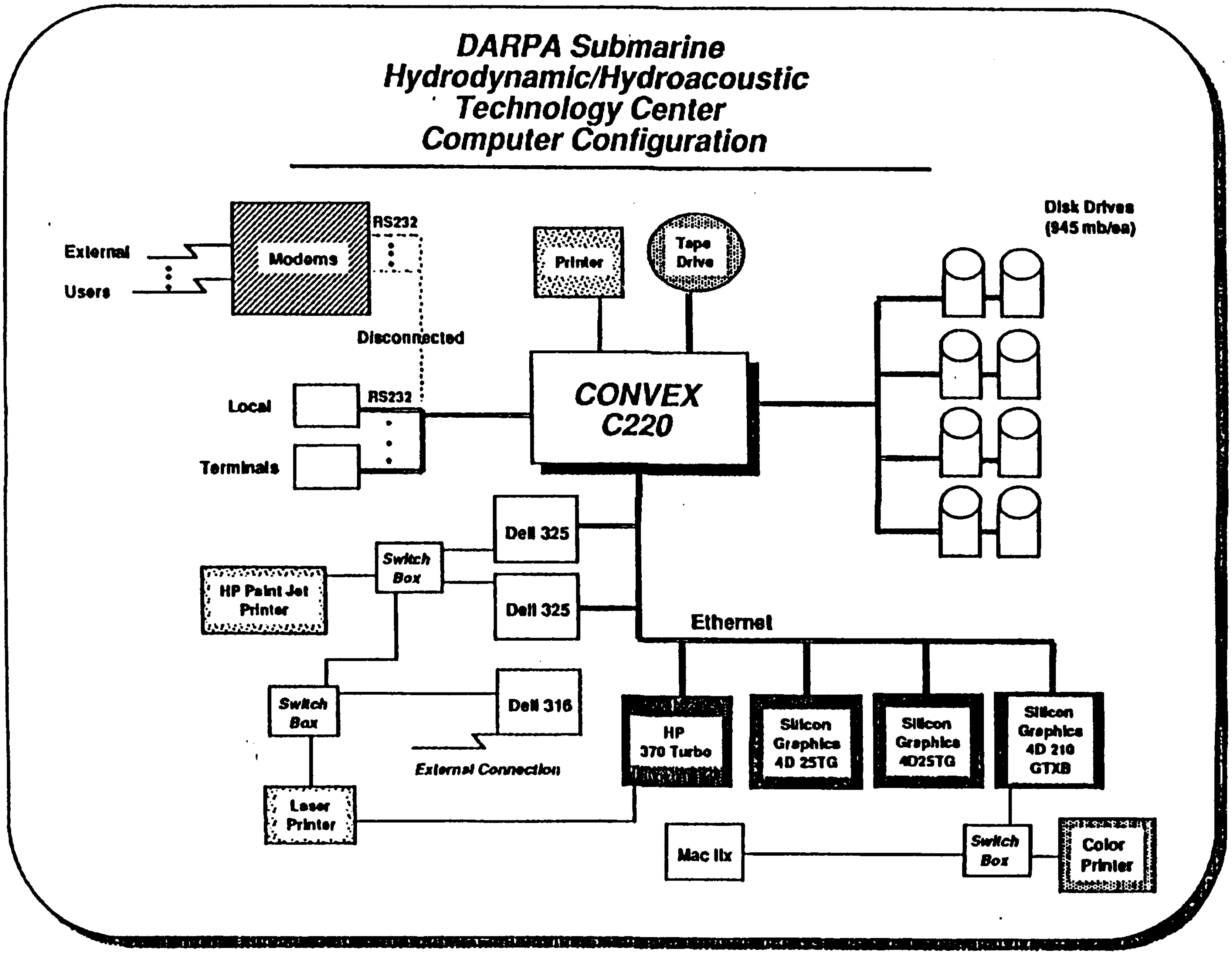


Figure 3. SH/HTC Computer Configuration

Connected to the CONVEX through the Ethernet are two Silicon Graphics 4D 25TG workstations, one Silicon Graphics 4D 210 GTXB workstation, a Hewlett Packard 370 Turbo, and the two Dell 325's. Storage capability includes eight 945 megabyte disk drives. In addition, a tape drive is available for the storing of programs or data not being utilized, thus allowing more disk space to be used for current projects.

Separate from the CONVEX network are a Dell 316 personal computer and a Macintosh Mac IIx. The Dell 316 has an external modem for access to outside computer facilities while the Mac IIx is a stand-alone system. The wiring for these systems consists of shielded cables under the false floor, including the Merlin voice telephone system that is utilized by the entire facility. All computer systems are certified to process up to the SECRET level.

Computer facility expansion is planned for the end of the summer of 1991 in order to increase available memory as well as reduce processing time. The CONVEX C220 will be replaced with a CONVEX C340 having four CPU's instead of two. Four additional disk drives of 945 megabytes will be added to the eight existing drives. The Silicon Graphics 4D 25TG and 210 will be replaced by three Silicon Graphics 4D 310 GTXB workstations. In order to allow encrypted remote access to the CLASSIFIED system, STU III Universals will also be installed. These units will be answer-only, operator-unattended, and will maintain a restricted list of external STU III's whose calls can be accepted. Figure 4 illustrates the proposed computer facility expansion.

The Center has many existing and prototype software codes to handle a variety of hydrodynamic flow and acoustical problems pertaining to submarine design in the four technical areas of interest. Table 2 is a summary list of available codes by name and corresponding function. In addition, a description of certain codes noted in the table by a star next to the code's name is listed in Appendix A.

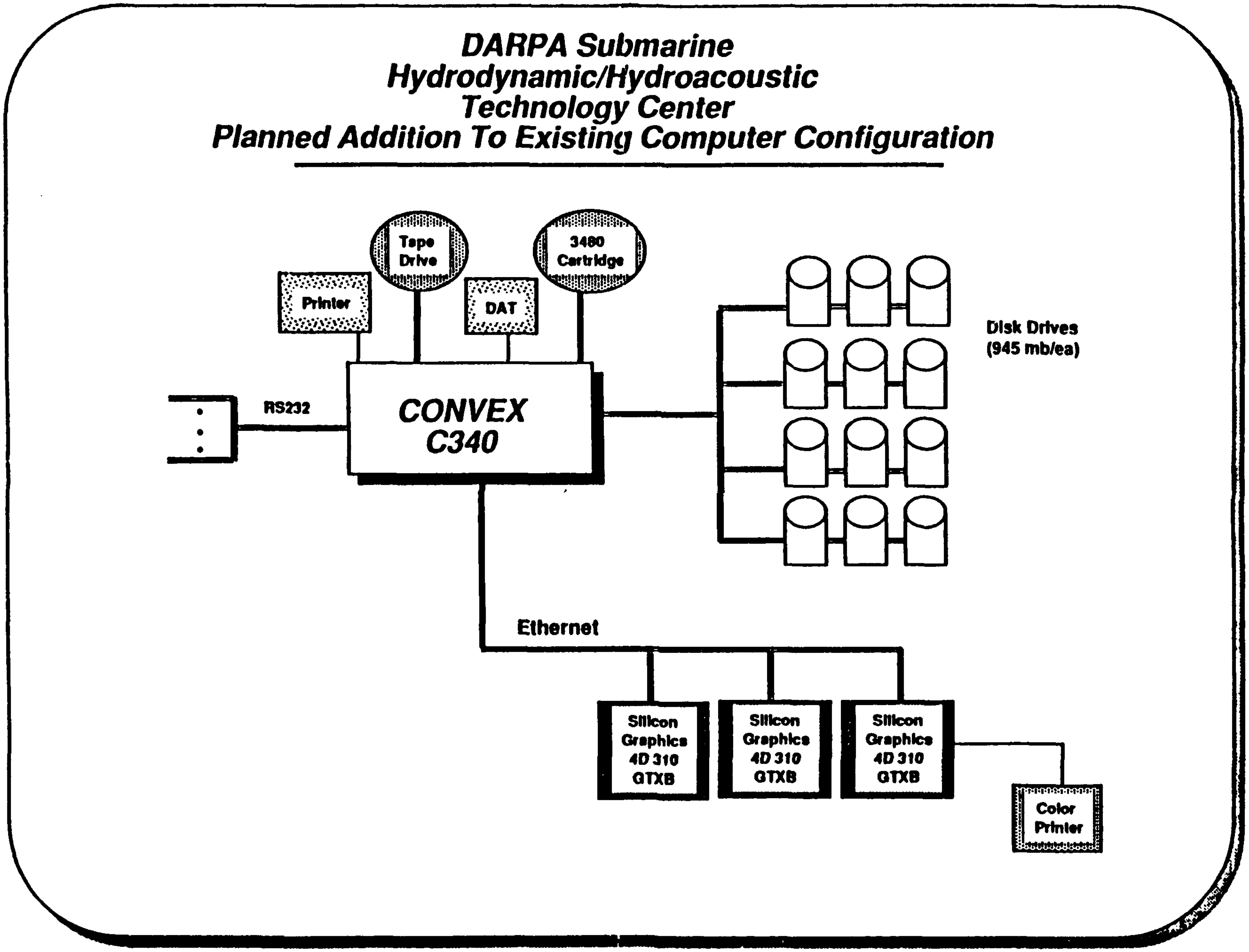


Figure 4. Proposed Computer Facility Expansion

TABLE 2. APPLICATION SOFTWARE AT SH/HTC

GEOMETRY/GRIDDING CODES

BLOCK3D - Grid generator
FASTSHIP or FAST YACHT* - Geometry generator
GRIDGEN* - 2D Grid generator
GRIDGEN3D* - 3D Grid generator
I3G* (sp) - Geometry generator
I3G* (dp) - Geometry generator
VIEW3D - Grid generator

GRAPHICS CODE

OMNIPLOT* - Interactive graphics program
PLOT3D* - Graphics program to visualize grids

POTENTIAL FLOW CODE

VSAERO* - Steady flow code

OTHER APPLICATION CODES

BBN-BBN* - Broadband noise of propeller and appendages code
CALCULATOR
DPUF-1 - Propeller unsteady flow code
GEORGE
SIMULATOR
SUBDES* - Submarine motion simulator
TRJV
TAPS* - Boundary layer transition code
PSF-10 - Propeller steady flow code
RANS - (Reynolds-averaged Navier-Stokes codes
DTN3D*, CFLOW, CRANS, FLOW1, ISFLOWB2, and ISFLOWB3

*Description of code in Appendix A. All other codes do not have documentation as of this time.

Table 3 is a list of PC software which is also available at the Center. Verification and experimental use of these codes is discussed in Section 3.3.

TABLE 3. PC SOFTWARE AT SH/HTC

DOS
EDGE - Engineering data graphing environment
Exp. Mem. Mgr. - Allows use of expanded memory
FORTRAN
FORWARN - Static source code analysis tool
MANIFEST - Memory analysis and reporting tool
MATLAB - Interactive scientific and engineering computation
Norton Utilities
S/W Carousel - Multi-program manager
Word Perfect - Word processor

3.2 SH/HTC Technical Research Areas

The following sections describe the Center's technical research activities in propulsor/hull design, maneuvering, hydro/structural acoustics and special studies.

3.2.1 Propulsor/Hull Design

The major concern with flow around an appended submarine is that non-uniformity in the propulsor inflow creates an acoustic design problem. One standard approach in studying the flow structure is to take measurements using models. Results are then scaled for full-size application. Reducing the effects of non-uniform inflow is accomplished by choosing the appropriate

number and skew of the propulsor blades. However, this is hampered by design constraints related to RPM, propulsive efficiency, and weight. Due to a lack of knowledge of the effective propeller inflow, computational methods are needed to accurately determine the non-uniform inflow to the propulsor to assess and analyze the effects of unsteadiness in the flow field as well as modifications in the submarine configuration.

The design of the propulsor is often limited because the propulsor inflow usually is determined by other design considerations. Therefore, modifications in the propulsor design are restricted. Improvements or modifications to the restricted propulsor design need to incorporate the spatial and temporal fluctuations of the inflow. Unfortunately, the accuracy needed in the computation of these fluctuations cannot be achieved since the spatial variations in the velocity field caused by variations in the submarine geometry and the ambient fluid are substantially larger than the required accuracy wanted.

The SH/HTC will be able to obtain accuracy on the order of ambient variations in the ocean once the final computer configuration is in place. In the interim, the problem of how to effectively remove spatial and temporal fluctuations of the propulsor inflow is being analyzed. Topics of research that could be performed by the SH/HTC in this area include:

- Reduction of wake defect by adjusting the upstream flow condition to alter the interaction of the flow with the appendages
- Designing the necklace vortex through modification of appendages to result in the vortex eroding the wake defect
- Interactive analysis of flow conditioning on propulsor performance, including unsteady forces needed for evaluation of radiated noise.

Research conducted to increase the performance of the propulsor must also take into account the hull flow since it directly affects the inflow to the propulsor. As with the propulsor inflow, the computational accuracies of the hull flow will be on the same order of magnitude as oceanic ambient variations. Use of innovative combined hull and propulsor geometries designed at the Center should result in reduced acoustic signatures and increased propulsor performance.

3.2.2 Maneuvering

The main focus in this area is the prediction of non-steady forces resulting from a submarine maneuver. It is also desired to relate these forces to modifications in the hull and appendage geometry as well as control surface settings. This capability should allow the safe operating envelope of submarines to be enlarged, thereby allowing for more benign handling qualities and greater stealth.

At present, many trajectories and maneuvers experienced in full scale cannot be accurately predicted or duplicated with existing simulation tools. In addition, the effect of proposed modifications to existing designs, including hull and appendage geometry modifications, on maneuvering characteristics cannot be accurately predicted. Using the Center's capabilities, evaluation of changes in maneuvering characteristics due to modifications in the hull or appendages will be able to be addressed. Futhermore, the investigation of such concepts as adding control surfaces to existing appendages (i.e., flaps behind the sail to remove roll in high-speed turns) will be possible once the appropriate capability has been implemented.

It is of significant importance to be able to understand the cause and effect relationship of a submarine maneuver. To date, the approach used has been to determine the coefficients of the equations modeling the dynamics using captive model tests and free running models. However, this does not provide an understanding of the effects of a maneuver. Capabilities of the Center will allow for insight into such behavior as well as:

- Evaluation of maneuver characteristics of proposed modifications to current designs; i.e., changes in appendages
- Investigation of maneuver characteristics of submarines in the preliminary design schedule
- Investigation of the effects on maneuvers when control surfaces are added to existing appendages.

3.2.3 Hydro/Structural Acoustics

Technological advancements have reduced the passive acoustic signatures of submarines to the extent that low- and mid-frequency active acoustics for detection, localization, and tracking have become of greater importance. Whether U.S. SSN and SSBN submarines are vulnerable to such methods is an area of intense study. As part of such a study, the analysis of the acoustic interface and the evaluation of active acoustics must be undertaken.

In analyzing the acoustic interface, the sound radiation field must be calculated, the response of the structure to a pressure field must be determined, and the relationship between sound radiation and the structural vibrations must be assessed. With active acoustics or the active control of acoustic radiation, the impedance of the structure must be modified for either a reflective (reactive) or absorbing (resistive) mode and the material properties must be modified to meet specified requirements. Examples of such modifications in material properties could be the addition of actuators embedded into composites. Additional computational requirements include the calculation of the target strengths of objects such as the shell and bulkhead and programs which compute the scattering and attenuation of the reflected acoustic field.

Calculating the target strength of elastic targets can be achieved by utilizing a wave equation in a homogeneous medium along with a 3-D elasticity theory equation incorporating boundary conditions dealing with small vibrations through the medium. Due to the complexity of solving these equations, a solution is usually obtained only by numerical methods.

Characterization of the acoustic target strength at both low and high frequencies is fairly well known. At the low frequency end, the wavelength is on the order of the diameter of the vessel, which can be set into vibration with several resonances being excited. At high frequencies, ray acoustics are applied. However, in the mid-frequency range, numerical methods and computational capabilities normally incorporated are not adequate. At this time, no national analytical or experimental capability exists for determining the mid-frequency target strength.

Increasing the database of target strengths of complex underwater objects in the mid-frequency range and establishing a framework for target strength analysis are the main goals of the Center in the area of hydro/structural acoustics. In addition, other goals of the SH/HTC are the analysis of the acoustic interface, the development of a turbulent boundary layer flow noise model, the development of new codes related to the turbulent boundary layer (TBL) excitation of structures, and system modeling for active control and acoustic scattering. As a consequence of these goals, the innovative application of the Center's high speed digital signal processing coupled with experimental data on active materials and target strengths will contribute significantly to the control of submarine acoustic signatures.

3.2.4 Special Studies

Special studies at the Center are to be intiated by both the Center and as identified by the Navy and intelligence agencies. The Center will primarily focus on the integration of software codes as tools for design engineers. Hence, the linking and integration of these various tools to solve certain intelligence-related submarine design issues will be another of the capabilities of the Center.

3.3 Experiments and Code Validation

The Panel Code Group of the SH/HTC has validated the VSAERO code (steady flow code) using SEAWOLF measured appendage forces, 688 velocity field, and SUBOFF body forces. The Group has also conducted density sensitivity studies and analyzed propeller inflow differences between LOS ANGELES (688) class and R&D (Memphis) submarine configurations. Comparisons between predicted and measured data are being analyzed regarding appendage forces for SEAWOLF, velocity field, and sailtip vortex trajectories for the 688 class and body

forces for bare hull and bare hull with fairwater for the SUBOFF configurations.

Reynolds Navier-Stokes Codes are also undergoing improvements and evaluation using SUBOFF experimental test data. Figures 5-11 are examples of the kinds of comparisons being made between the RANS Code calculations and experimental results. The agreement between the calculations and experimental data is very good, especially in the cases of the pressure distribution and surface pressure of the SUBOFF bare hull and ring wing. This is shown in Figures 7 and 8, where it can be seen that the RANS Code correlates better with the experimental data than the VSAERO Code, as one would expect. In the case of the SUBOFF bare hull and ring wing axial velocity and turbulent kinetic energy (TKE) calculations (Figures 5, 6, 10, and 11), the computational model closely follows the experimental data. Improvement in accuracy of the modeling of the ring wing axial velocity and TKE is obtained using a finer computational grid as illustrated in Figures 10 and 11.

To enhance the efficiency of CFD calculations, a common gridding system is being developed and refined for all RANS codes in use at the SH/HTC. The basis for the gridding system is the code GRIDGEN. Code validation is being accomplished through pre-test analyses of sting/strut experiments and pre-test computations for interacting vortices.

In the propulsor area, the Code PSF-10 was validated using open water test data on propellers 4119, 4718, and 4679. The results of the tests for propeller 4119 are shown in Figures 12-14. Agreement between experimental data and the model using the panel method for the performance curve, pressure distribution, and velocities was excellent. These results were subsequently compared with calculations from VSAERO. DPUF-1, a propeller unsteady flow

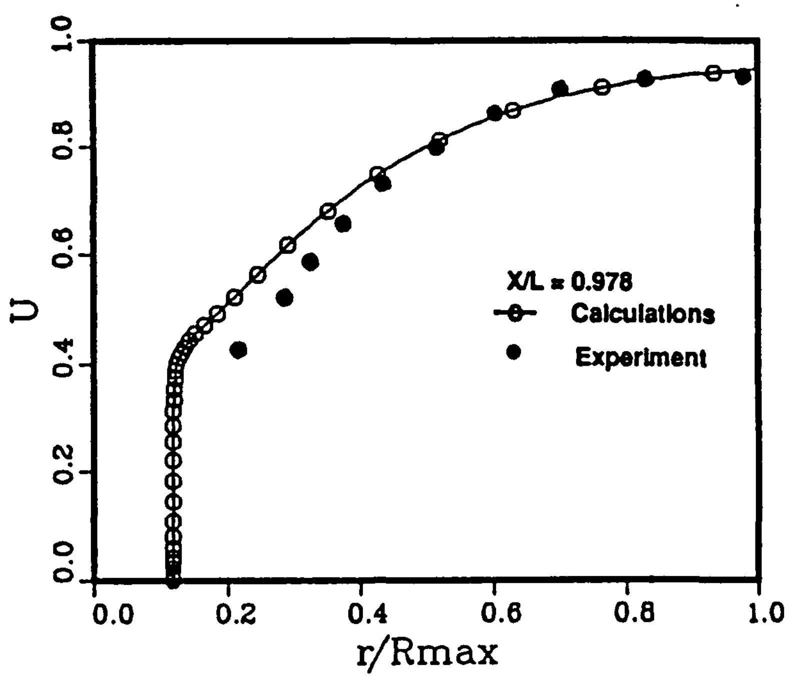


Figure 5. SUBOFF Bare Hull Axial Velocity

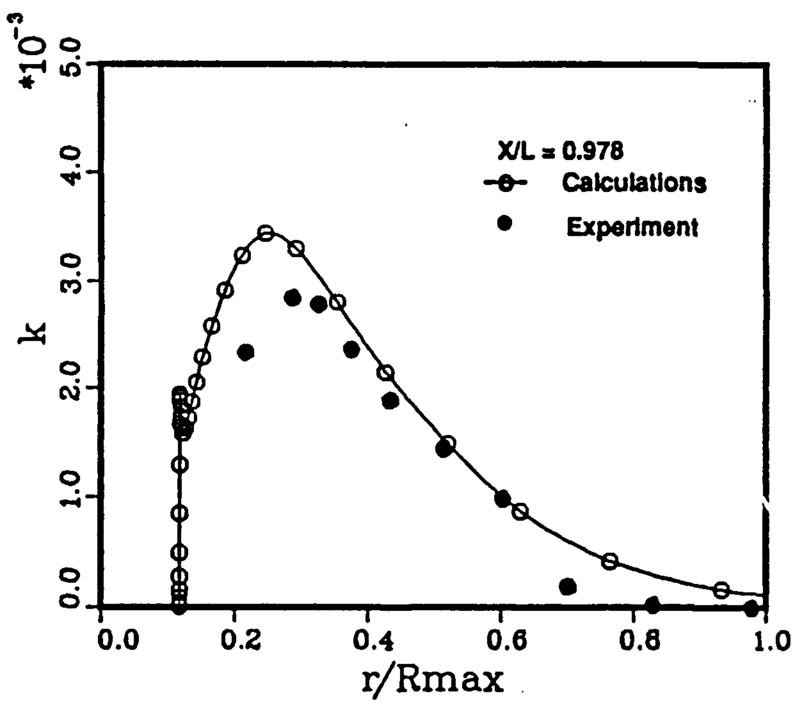


Figure 6. SUBOFF Bare Hull Turbulent Kinetic Energy

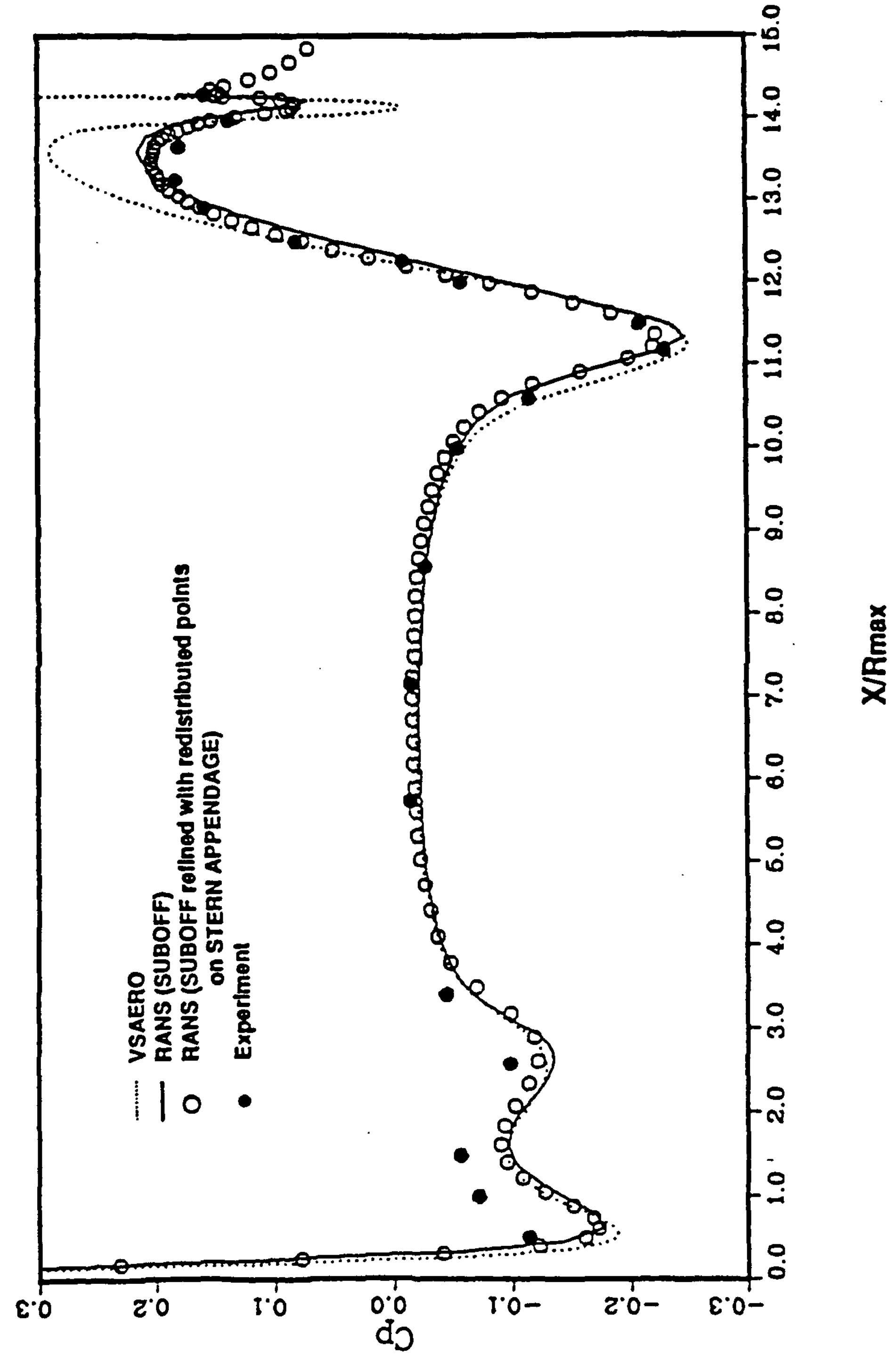


Figure 7. SUBOFF Bare Hull Pressure - RANS vs AERO

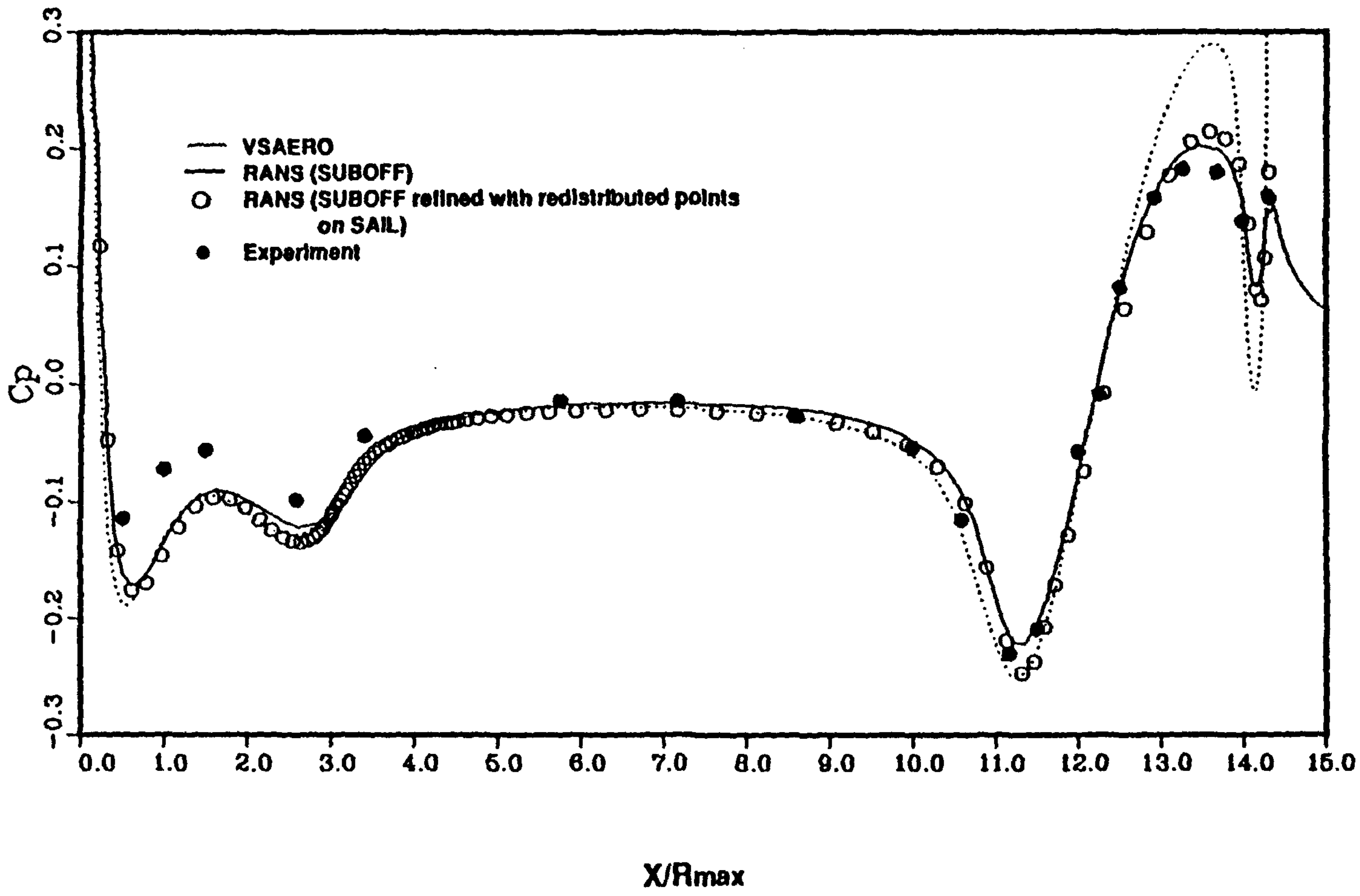


Figure 8. SUBOFF Bare Hull Pressure - RANS vs AERO

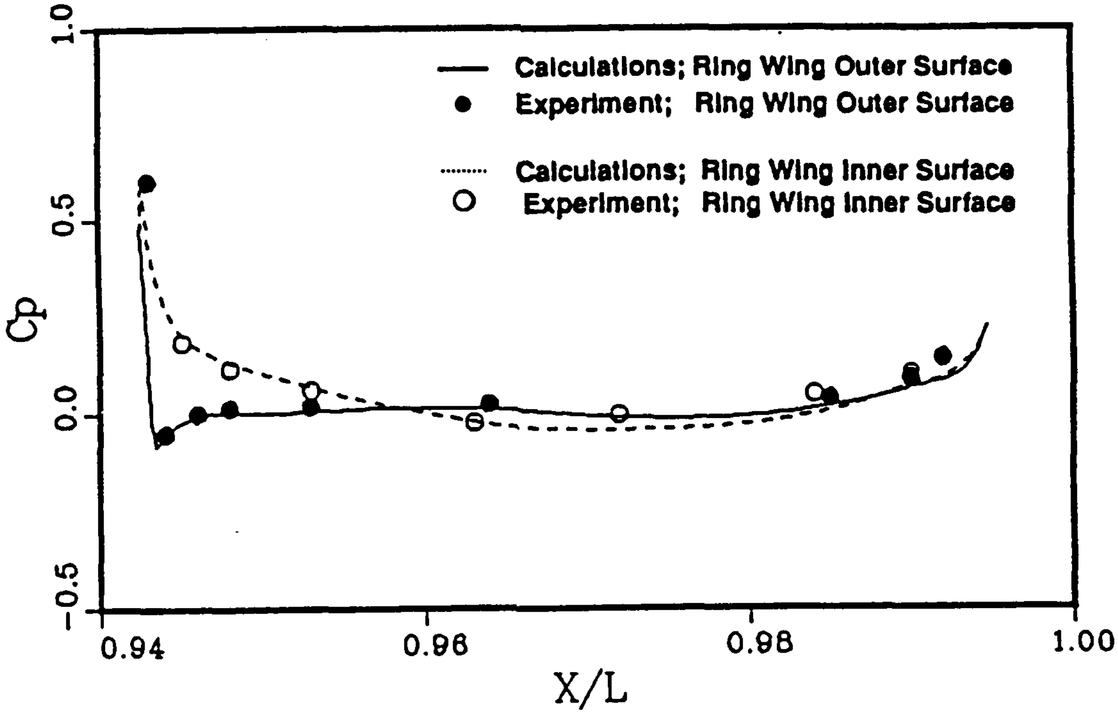


Figure 9. SUBOFF Ring Wing Surface Pressure

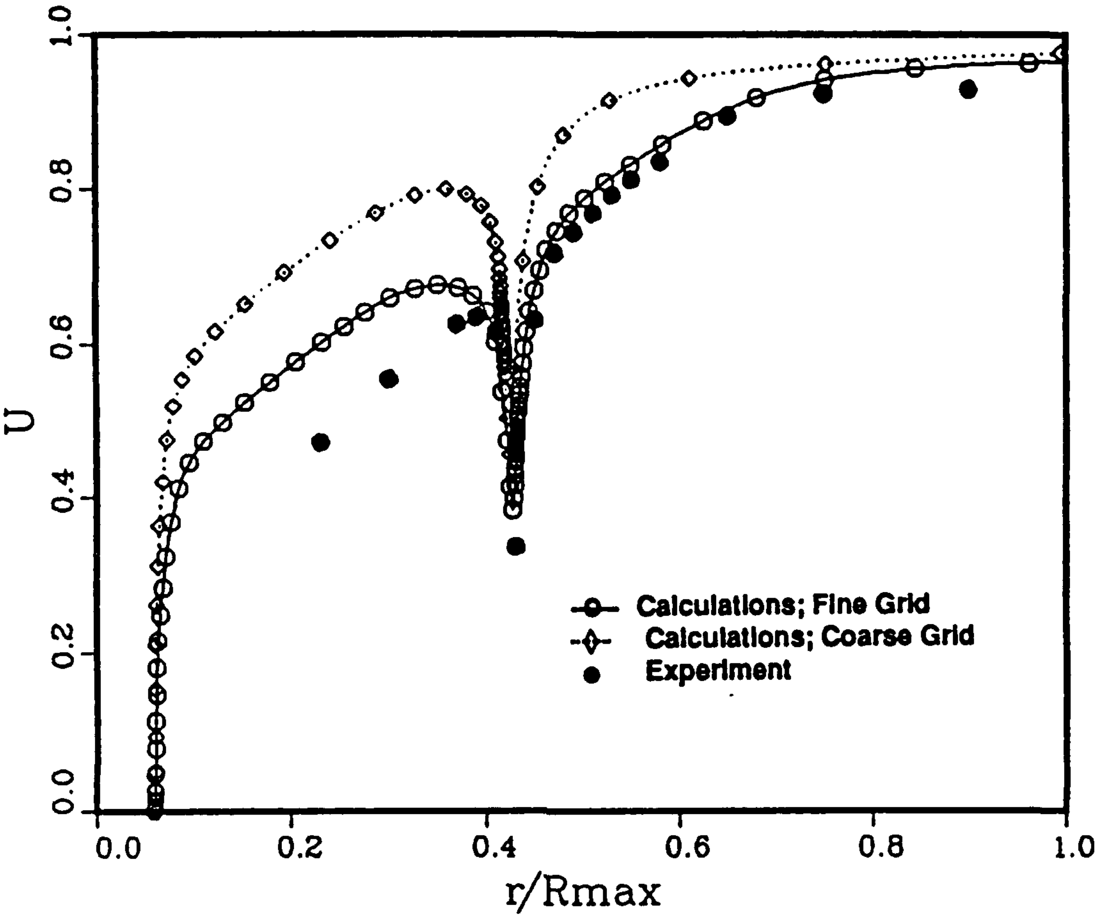


Figure 10. SUBOFF Ring Wing Axial Velocity

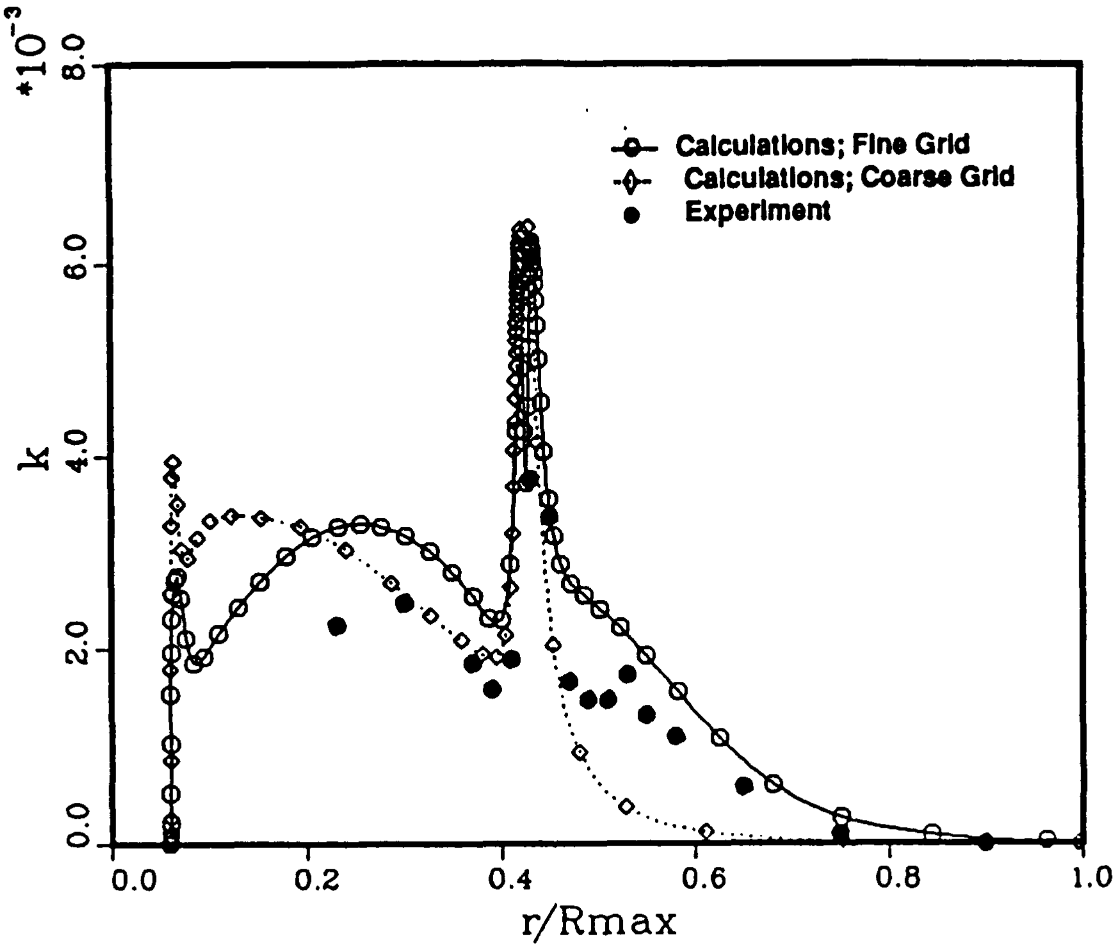


Figure 11. SUBOFF Ring Wing Turbulent Kinetic Energy

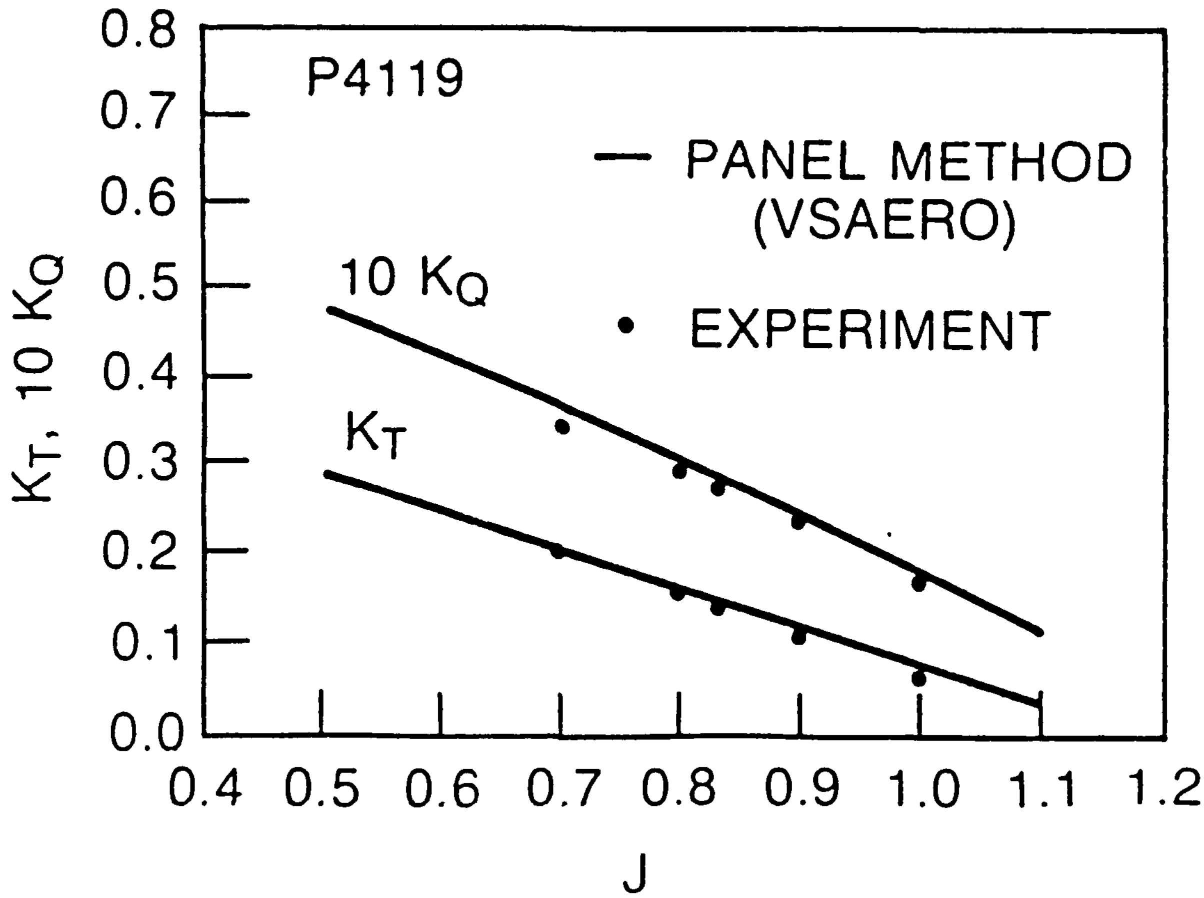


Figure 12. Open Water i erformance Curve - Propeller 4119

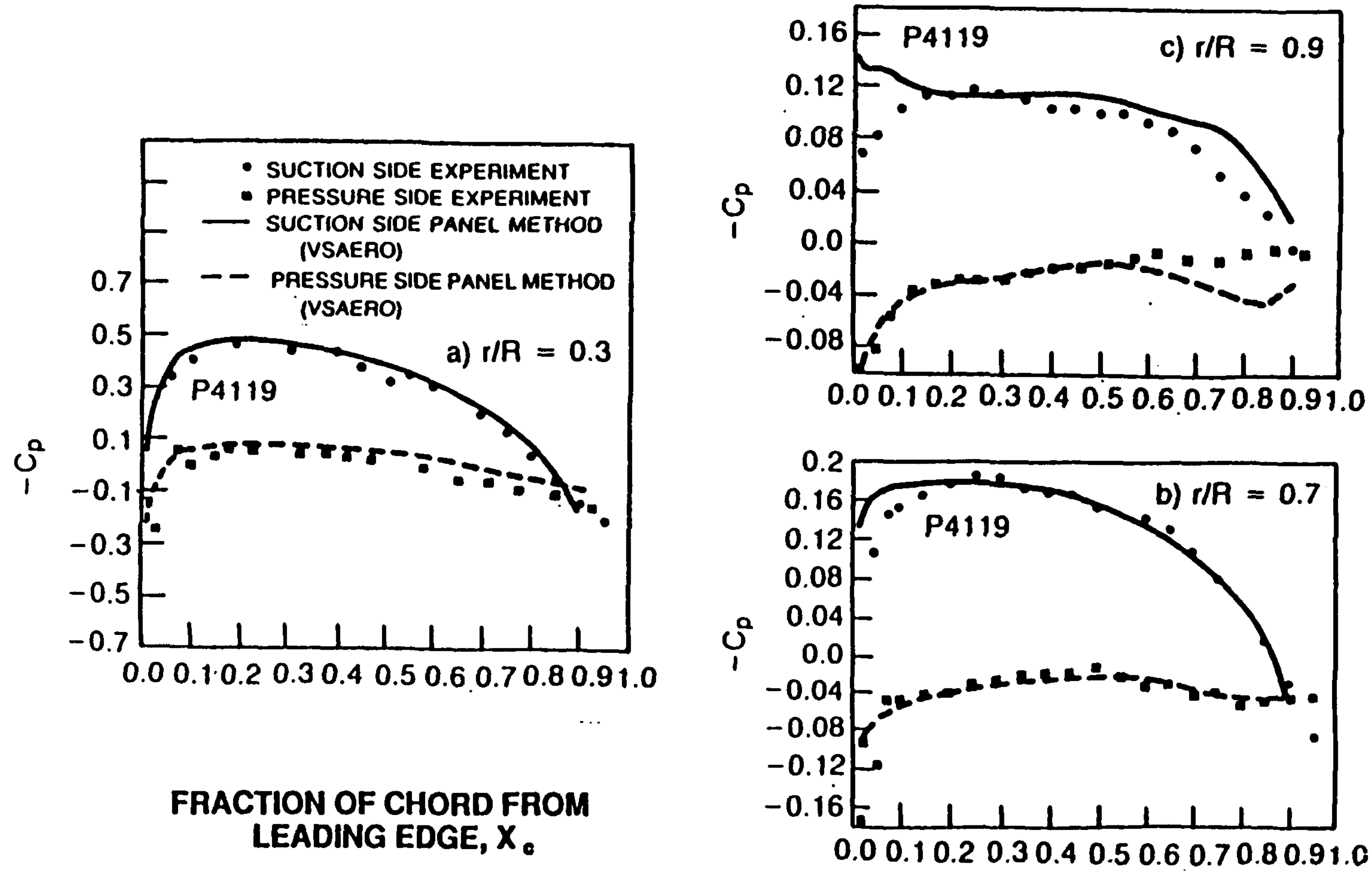


Figure 13. Comparison of Measured and Predicted Pressure Distribution at Design Condition for Propeller 4119

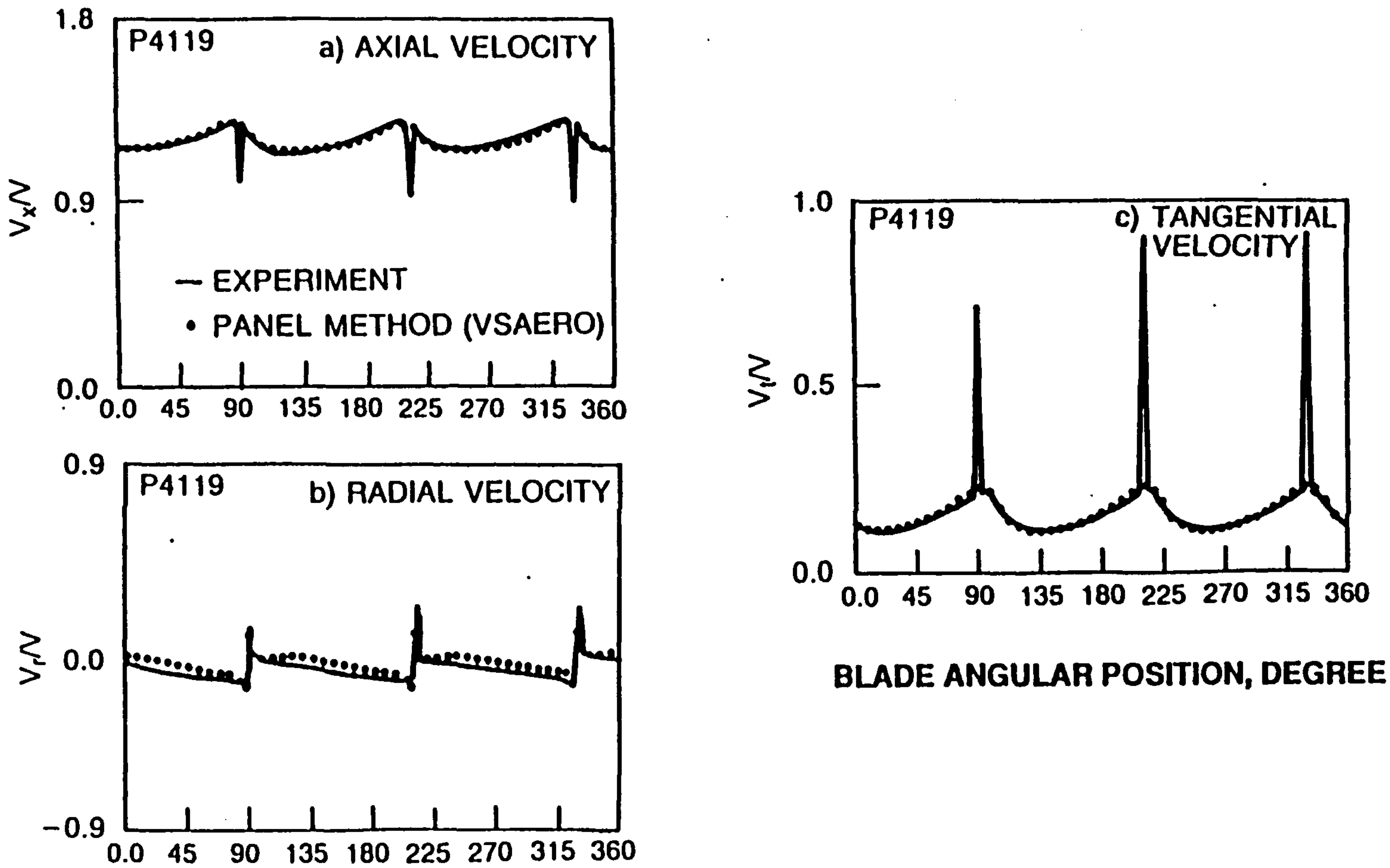


Figure 14. Comparison of Measured and Predicted Pressure Distribution at Design Condition for Propeller 4119 at 0.7 R

code, is scheduled to be validated using the ARL stator/rotor test data, which is due in FY 92. Flow measurements behind the stator will be used as input for the DPUF-1 code to predict the unsteady force on the rotor.

In the area of maneuvering, codes received from Aeronautical Research Associates of Princeton (ARAP) were validated using SSN 688 full-scale, RCM, and captive model data; SEAWOLF RCM and captive model data; and LSV RCM and captive model data. Pre-test analyses of RCM laser light sheet trajectories were also conducted. Comparisons are being made between predicted and measured data for: maneuvering coefficients for 688, SEAWOLF and LSV; trajectories vs math model or RCM trajectories for 688, SEAWOLF and LSV; and trajectories vs full scale trajectories for 688 class submarines.

In the area of special studies, research has been performed for the SSN 688 and R&D Submarine. First, 6-DOF calculations were completed for the two submarine configurations and the resulting differences in trajectories, forces, and moments were documented. Using the calculated propulsor inflow from a potential flow/boundary-layer code, the forces and moments transmitted to the hull via the propeller shaft, the noise radiated from the 688 and R&D submarines, and the blade-rate related to fluctuation forces and moments on the propeller blades were computed and analyzed. An interactive hull-propulsor calculation using a 2-D axisymmetric IIHR Code with propulsor effects was also performed on both configurations in addition to radiated noise calculations. The basis for these computations was to assess the changes in geometry between the two configurations.

An overall experimental summary is contained in Appendix A. Each summary lists the objective, issues, instrumentation, facilities, and dates for each individual experiment.

4.0 CURRENT SH/HTC ENGINEERING R&D ACTIVITIES

This section presents a summary description of the current SH/HTC engineering R&D activities in the four main technical areas of interest. Schedules and major milestones for these activities are also presented.

4.1 Propulsor/Hull Flow

For propulsor-hull interaction and hull flow, the following tasks are being undertaken:

- Development of high order numerical schemes such as spectral methods to solve the RANS equations
- Development of a methodology to systematically generate unstructured grids along with an accurate numerical procedure for solving the flow equations
- Development of an effective multi-block grid system
- Assessment of the improvement in turbulence modeling when employing the full Reynold's stress transport equations by using an inviscid panel code such as ARAP's WAKE Code
- Determination of the usefulness and limitations of the potential flow/boundary layer approach in modeling the inflow to the propulsor
- Development and validation of interactive 3-D propulsor codes such as the IIHR Code that deals with ducted and multistage propulsors

- Conduct of propulsor-hull interaction studies for the design of innovative combined hull and propulsor geometries utilizing hydrodynamic and acoustic codes
- Development of zonal methods and advanced turbulence modeling to resolve the detailed blade-to-blade flow such as laminar and turbulent blade boundary layers, blade wakes, and leading-edge, tip, passage, and hub vortices
- Development of grid generation techniques for embedded moving grids for use with propulsor flow calculations
- Conduct of a parametric study to investigate the effect of changes in the appendage geometry and upstream flow condition on the inflow to the propulsor using RANS codes
- Identification of ways to remove spatial and temporal flow non-uniformity in the propulsor inflow
- Concept analysis of boundary layer flow injection/suction to control the flow distribution.

4.2 Maneuvering

In the area of maneuvering, the following tasks are being performed:

- Validation of 6-DOF maneuvering codes by performing calculations of trajectories, force, and moments for configurations such as SSN 688, SSN 21, LSV, and R&D Submarine
- Conduct of pre-trial analysis before each experiment. Examples of such analysis include the computation of trajectories for the RCM laser light sheet test and experiments using the SUBOFF

configurations, the MIT oscillating foil, calculation of forces and moments on the sting/strut, and the rotating arm for analyzing high angle of attack.

4.3 Hydro/Structural Acoustics

Tasks in the hydro/structural acoustics area include:

- **Definition of target model for bistatic scattering calculations--** The model will represent a submarine hull without appendages. Mechanical properties of the bulkheads, the shell, and the stiffeners along with their dimensions will be known.
- **Performance of bistatic scattering calculations on a rigid shell with the same dimension as the target model using an existing boundary-element code--**Determination of the high frequency limit at which the code cannot be efficiently used in the existing computing environment. Improvment of the performance of the code through better formulations, such as using variational expressions for the scattering amplitude and more efficient numerics.
- **Calculation of bistatic scattering for the same rigid shell for low frequencies using results from the method of matched asymptotic expansions and comparison with results from previous experiment--** Analytic investigation and comparison with numerical results of the validity of bistatic scattering predictions from the method of matched asymptotic expansions for the same target in the intermediate frequency regime where the acoustic wavelength is comparable to the diameter of the target.

- Computation via finite element code of the *in vacuo* response of normal velocity of the target model when acted upon by an incident harmonic pressure field--Variation of the frequency to reach the limit of the code capability in the existing computing environment. Investigation of the fidelity and efficiency of using equivalent impedances attached to appropriate nodes for the stiffeners and bulkheads.
- Construction of a simplified mechanical model of the target model in the low frequency regime by approximating it as segments of a simple or orthotropic membrane with joint conditions applying at locations of the bulkheads derived using the method of matched asymptotic expansions--Solution of the equations for response of normal velocity to incident pressure field and comparison with results from the previous task.
- Computation of the bistatic scattering of the target model using an existing boundary-element/finite-element code--Variation of frequency to reach the limit of code capability in the existing computing environment. Improvment of the performance of the code, with or without equivalent impedances for the stiffeners and bulkheads, through better formulations and more efficient numerics.
- Investigation of the extension of the geometrical theory of diffraction to elastic targets similar to the target model in the mid-frequency range where the acoustic wavelength is comparable to the spacing between stiffeners--Computation of diffracted rays and radiation impedances by considering local scattering. Implemention of the theory as a computer code. Computation of bistatic scattering from target model using the code.

- Modification of codes to allow the computation of radiation from target model when driven by a fluctuating force other than an incident pressure wave.

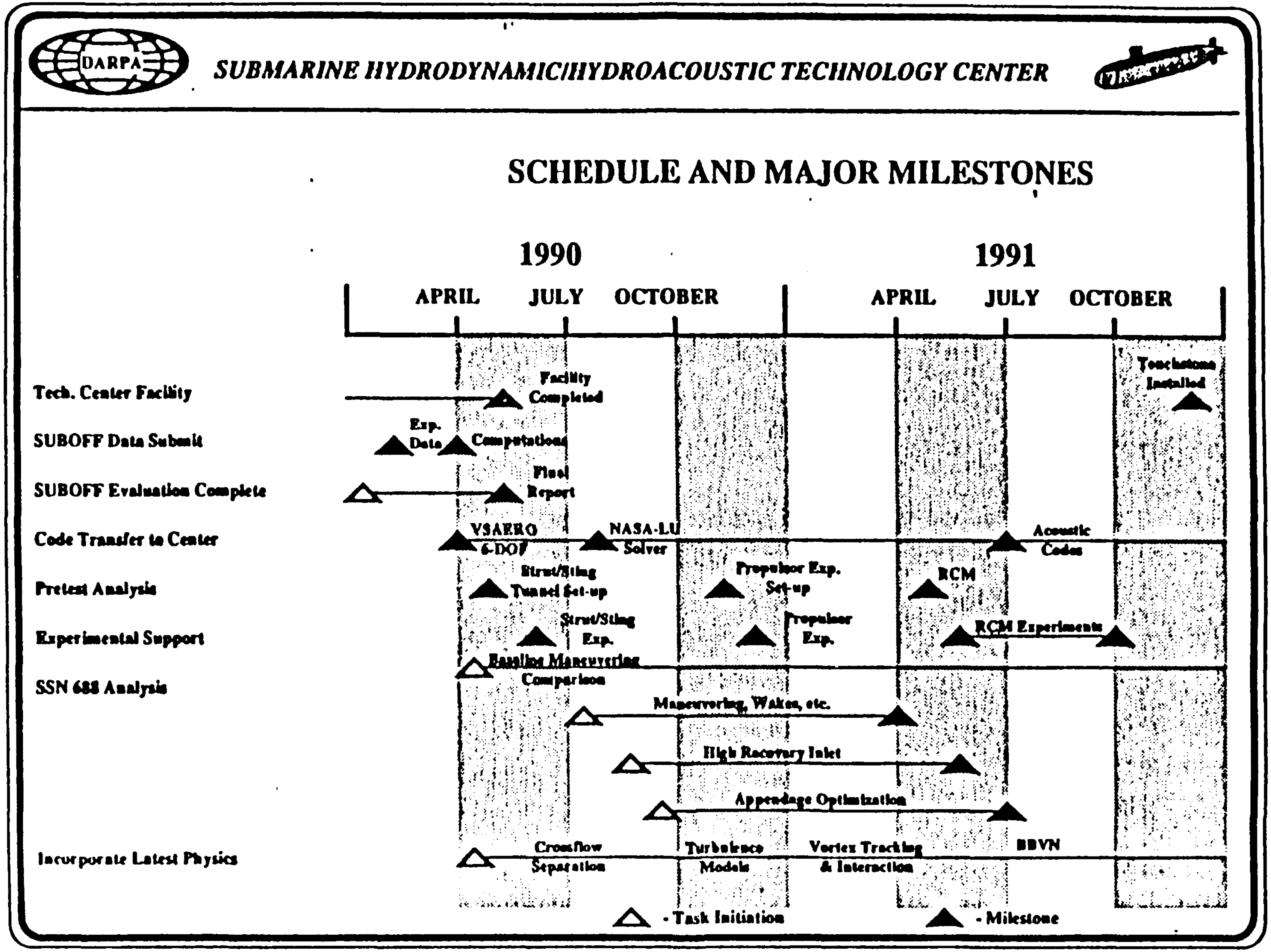
4.4 Special Studies

Tasks being undertaken in the area of special studies are the following:

- RANS code modification and improvement
- Analysis of foreign platforms that have unusual appendages or protrusions.

4.5 Major Milestones of the SH/HTC

Schedule and major milestones for SH/HTC research activities are shown in Figure 15. The figure shows experiments and analysis that have been conducted or are still in progress. Essentially all panel, propulsor, RANS, and maneuvering codes are to be validated by the beginning of the summer of 1991.



H-0197-1/22/90

Figure 15. Schedule and Major Milestones for SH/HTC

5.0 PLANNED RESEARCH ACTIVITIES

An important task to be addressed at the SH/HTC in the near future includes the integration of selected codes to access common geometry data bases. A CAD system will be installed and developed to allow for geometric integration. Software which utilizes massively parallel computing capabilities is to be developed and integrated resulting in faster processing times and the ability to run more codes concurrently. Also planned is the validation and incorporation of the unsteady panel code plus the incorporation of hydroacoustic analyses of hull, appendages, and propulsors into the family of available codes of the Center. Increased interaction between the Center and the structural-acoustics community is expected to aid in the assessment of new technologies in that area.

Specific technology-driven capabilities are planned to improve the Center's computational capability. Present capabilities invoke structured grids, utilize a two-processor vector compiler, 1/2 gigabytes of core memory, 100 megaflop performance, and classified computing to the SECRET level. Planned for the future are adaptive/unstructured grids, parallel CFD algorithms, memory expansion (>2 gigabytes), a scalable/expandable operating system (MACH), increased computer power (Touchstone, 6-30 gigaflops), and a heterogeneous multi-level security system (NECTAR, TMACH).

6.0 REFERENCES

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APPENDIX A

SUMMARY OF EXPERIMENTS AT THE SH/HTC

OBJECTIVE:

- Validate experiments with existing databases (German)
- Measure separation at large angles of attack
- Characterize transition as function of Re
- Measure vortex paths
- Compare separation measurements by VPI hot film rosettes and PDV

MODEL:

- 6:1 Ellipsoid
- Follow on with SUBOFF body with various appendage configurations

FACILITY: DTRC 140' tank (Tommy Huang, Joe Katz [APL])

INSTRUMENTATION:

- PDV, ~1000 VPI hot film arrays - no forces

ISSUES:

- Calculations of vortex trajectories, separation and transition required
- Data management system for access to large amount of data

DATES:

- Preliminary results end of February, 1991

Figure A-1. High Angle of Attach (post SUBOFF HAOA)

OBJECTIVE:

- Determination of steady separation line to tie into existing database.
- Study of unsteady separation for the plunging model

MODEL: 6:1 Ellipsoid - Sting mounted plunging model

FACILITY: VPI Wind Tunnel/ plunging model facility

INSTRUMENTATION:

- Hot wires, forces and moments measurements
- LVD mounted internal to model

ISSUES:

- Unsteady calculations in support of experiment
- Possible test of new shear stress probes (32 rosettes per sheet)

DATES:

- Start date not determined, possibly April 1991

Figure A-2. Separation Study (VPI/ONR)

OBJECTIVE:
- Complete characterization of interaction of a pair of longitudinal vortices
- For validation of turbulence models

MODEL: Pair of rectangular planform wings (NACA 0012, square tip) at differential, variable angles of attack

FACILITY: VPI Wind Tunnel
- (tracking of vortices for over 50 chord lengths)

INSTRUMENTATION:
- Hot wire - complete flow field characterization including vortex core pressure and shear stresses.

ISSUES:
- Test plan coordination with calculations using various turbulence models to set measurement planes and resolution.
- Preliminary tests for single foil have been started, and show that the vortex core is stable along the full tunnel test section.

DATES:
- End of preliminary tests on single wing February 1991
- Start date for interacting vortices April 1991

Figure A-3. Interacting Vortices

OBJECTIVE: Complete characterization of flow field, including full unsteady flow.

MODEL: 18', 688

FACILITY: Maneuvering and Seakeeping Basin

INSTRUMENTATION:

- Conventional - trajectory, thrust, torque, control settings, ship states
- Complete flow field, including separation & vortex paths, through PDV
- Forces on segments of afterbody and forces on control surfaces
- LDV for flow at propeller plane using 5 laser probes within propeller hub.

  The LDV measurements are not performed simultaneously with the force and moment measurements
- Surface pressures

ISSUES:

- What is a sensible test program with respect to code validation?
- Development of a configuration management plan to handle access to massive amount of data.

DATES:

- Shakedown tests - April 1991
- Follow-on tests - July 1991

Figure A-4. Radio Controlled Model (RCM)

OBJECTIVE:

- Widen state space for captive model tests for maneuvering forces and moments
- Test new VPI hot film probes

MODEL: 688, sting mounted on rotating arm

FACILITY: DTRC /rotating arm

INSTRUMENTATION:

- ~1000 VPI hot film arrays (rosettes)
- Forces and moments as digital data, time sequenced with data from hot wire rosettes.

ISSUES:

- Calculation of separation
- Sting interference efforts on body/appendage forces and moments
- Analysis of sensitivity to flow topology (separation lines, vortex paths)

DATES:

- Start postponed indefinitely

Figure A-5. Rotating Arm

OBJECTIVE:

- Study of effect of unsteady vortices on a nearby foil

MODEL: Two upstream pivoted foils mounted above and below an instrumented wing section

FACILITY: MIT tunnel

INSTRUMENTATION:

- Flow visualization, forces and moments

ISSUES:

- Calculations using inviscid codes are being performed now.

DATES:

- First test phase completed by July, 1991

Figure A-6. Gust Experiment

OBJECTIVE: Extend numerical codes, flow models and physical understanding of multiple blade row propellers at large chord Reynolds numbers.

MODEL: 42 inch diameter pump - inlet guide vanes (IGV)/rotor/optional stator

FACILITY: Penn State HIREP Facility

INSTRUMENTATION:

(a) Steady
- Static pressures on rotors and IGV
- Total pressures upstream and downstream of rotor
- 2 component LDV, 5 hole probe
- Surface flow visualization and cavitation

(b) Unsteady
- Unsteady static pressure on rotors and stators
- Unsteady forces and moments at blade rate and higher harmonics on shaft, casing and blades.
- Accelerometers for vibration levels on blades.

ISSUES:
- Vortex interaction between stators and rotors
- Transition measurements
- Follow-on study for open propeller

DATES:
- Start steady tests December, 1990
- Start unsteady tests August, 1991

Figure A-7. HIREP Propulsor

OBJECTIVE: Study passive and active methods for controlling propulsor inflow and the resultant unsteady forces, particularly for blade rate noise and harmonics

MODEL:
a. Airfoil with slotted trailing edge
b. Five blade fan using blowing from upstream struts
c. Five-blade fan with baseline duct and variable tip gap ducts.
d. Test of active control through adaptive feedback.

FACILITY: Benchtop experiments initially

INSTRUMENTATION:

- Hot wire, flow visualization and forces initially..

ISSUES:

a&b • Substantiate calculations, experiments showing beneficial effects of suction/blowing

c. • Demonstrate passive and active control through variable tip clearance and validate codes.

d. • Validation of code predictions for active control of unsteady flows.

e. • Coupling to acoustic codes.

DATES:

- Test plans complete in September, 1991

Figure A-8. Propulsor Inflow Control

APPENDIX B

DETAILED DESCRIPTION OF COMPUTER CODES AT THE SH/HTC

APPENDIX B

DESCRIPTION OF COMPUTER CODES AT SH/HTC

- GRIDGEN--This code provides an efficient means of developing a multiple block grid for complex configurations. The code actually consists of three sub-codes GRIDBLOCK, GRIDGEN2D, and GRIDGEN3D. GRIDBLOCK is used to develop blocking structures and set interblock connections; GRIDGEN2D to generate surface grids on the six faces of each block; and GRIDGEN3D to generate volume grids in the interior of each block. The GRIDBLOCK and GRIDGEN2D codes are written for the Silicon Graphics IRIS workstation.

- I3G--The Interactive Graphics for Geometry Generation (I3G) Program provides a single facility linking several geometry data sources to any of a wide range of analysis codes. The code simplifies and speeds up the creation of geometry models for input to various aerodynamic analysis codes and applies modern interactive computer graphics and database management to allow rapid manipulation and formatting of surface definition data stored in a "code-independent" format. Also, since the user graphically views the data as a model is being constructed, it is easier to detect and correct any errors.

- OMNIPLOT--This program is a color interactive graphics program developed to display the results of an aerodynamic panel method. The data file is typically produced by VSAERO but other panel codes can be used. The displayed information can be aerodynamic data on the body surface or in the flow field, body and wake geometry, streamline trajectories and conditions, and boundary-layer characteristics. Bodies with up to 6000 panels can be handled with multiple solutions contained in one data file.

- PLOT3D--This program is a computer graphics program designed to visualize the grids and solutions of computational fluid dynamics

codes. Eighty-seven functions exist and the program is available for several systems. PLOT3D can read multiple grids with almost any number of grid points rendering models as wireframe, flat shaded, or color-mapped. Shading and perspective are used to show depth. Output from the program is displayed on a workstation screen and is easily manipulated with a mouse. Files can be created for scripting PLOT3D or for driving various printers and plotters.

- VSAERO--This code is used for calculating the nonlinear aerodynamic characteristics of arbitrary configurations in subsonic flow. Nonlinear effects of vortex separation and vortex surface interaction are treated in an iterative wake-shape calculation procedure, while the effects of viscosity are treated in an iterative loop coupling potential flow and integral boundary layer calculations. The basis for the code is a surface singularity panel method using quadrilateral panels on which doublet and source singularities are distributed in a piecewise constant form. The panel source values are directly determined by the Neumann boundary condition controlling the normal component of the local flow and the doublet values are solved after requiring the equivalent flow to be irrotational and incompressible. Surface perturbation velocities are obtained from the gradient of the doublet solution, while field velocities are obtained by direct summation of all singularity panel contributions.

- FASTSHIP--This program is a computer-aided design package specifically tailored to the needs of ship/yacht designers. By having many of the ship design functions integrated into a single package, a design environment is created in which preliminary concept and design work can grow systematically into progressively more detailed design and analysis.

- BBN-BBN--This code is used for predicting the broadband noise radiated by propellers and appendages. Direct noise levels are

computed and correspond to the radiated sound that would be measured if the propulsor and hull were rigid surfaces. BBN-BBN also computes the broadband unsteady hydrodynamic forces on lifting surfaces. Total radiated sound can be predicted by adding to the forces computed in BBN-BBN the structural transfer function, or gain, which relates blade forces to radiated sound.

- SUBDES--SUBDES is a submarine motion simulator program that implements the equations of motion developed under IR&D at Electric Boat Division using experimental data and analytical techniques. The SUBDES equations are implemented in two computer programs: CALCULATOR and SIMULATOR. CALCULATOR calculates all the geometry dependent non-time varying hydrodynamic and inertia terms and stores them in a file. SIMULATOR uses the data file generated by CALCULATOR and a run file generated by the operator to perform motion simulations of the selected configuration.

- TAPS--The Transition Analysis Program System (TAPS) is a digital computer program designed to facilitate the prediction of boundary layer transition using stability analysis theory. The program handles axisymmetric and two-dimensional bodies in air and water. The program contains four basic types of components: (1) geometry, (2) potential flow, (3) boundary layer, and (4) stability analysis. The potential flow program components were derived from the Douglas Axisymmetric and Two-Dimensional Neumann programs. The boundary layer program component is based on the Cebeci-Smith finite-difference boundary layer program and uses the Keller box method for solving boundary-layer equations.

- DTNS--The David Taylor Navier-Stokes (DTNS) codes are used to solve the incompressible Navier-Stokes equations using pseudo-compressibility. The three versions of the code are: two-dimensional (DTNS2D), axisymmetric (DTNSA), and three-dimensional (DTNS3D) calculations. Presently, the codes can only be used for doing steady-state calculations.